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## GENERATING WEATHER DATA FOR LINEAR WEAPONS ALLOCATION MODELS

STRIKE PROCESS STUDIES BRANCH  
WEAPON SYSTEMS ANALYSIS DIVISION

JUNE 1975

FINAL REPORT FOR PERIOD  
JANUARY 1975-JUNE 1975



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# PREFACE

This report documents an in-house effort performed during the period from January 1975 to June 1975 by Captain James V. Blowers for the Strike Process Studies Branch (DLYA), Analysis Division. The effort was accomplished under JON 2543-02-01.

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

J. R. MURRAY  
Chief, Analysis Division

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## SECTION I

### INTRODUCTION

An important factor in the execution of military operations is the weather at the scene of the battle. Whether or not air operations can be undertaken (and which ones) depends on the ceiling and visibility conditions. Therefore, many weapons allocation models have a capability for simulating these conditions. These conditions are determined for the most part by launch envelopes of aircraft-missile systems. For instance, steep dives require high altitudes. If the ceiling or visibility is low so that the pilot cannot see the target, then the maneuver cannot be accomplished. It is therefore desirable to have a convenient method for computing the probabilities of conditions for different types of sorties.

This report presents a method for generating these probabilities. The weapons model for which this method was intended to be used is a linear programming model written by Robert Speir (Reference 1); however, it probably can be used for many other weapons allocation models. The method consists of a program in FORTRAN IV for the CDC 6600 which converts data given by the Air Weather Service (AWS) for a given location into data that fit the launch envelopes of various weapon systems. The location used in this report was Berlin, Germany.

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1. Speir, Robert A., Another Linear Programming Approach to USAF Conventional Weapons Planning. AFATL-TR-73-201, Eglin AFB, Florida, 1973.

## SECTION II

### DESCRIPTION OF PROBLEM

In order to be able to tell a weapons allocation model whether the weather is good enough for a given weapon system to fly its sorties, there must be a reasonably good method of predicting the weather at the scene of the battle. Unfortunately, methods for predicting weather states months or years in advance do not exist; hence, only probabilities can be dealt with. A set of data describing the probability of given weather states (in terms of ceiling and visibility conditions) would thus be desirable. Such a data base is given by the Air Weather Service. For a given ceiling level C and visibility level V, the AWS data advance the probability that in a given 3-hour period in a given month the ceiling will be at or higher than C and the visibility will be at or higher than V. However, this may not be compatible with the requirements of the allocation model. The model may require ceiling levels or visibility levels that are not given in the AWS tables, and the conditions for using certain weapon systems may not be of the form "ceiling is greater than or equal to C and visibility is greater than or equal to V." Hence, a method for converting the AWS data into data giving the probabilities that conditions for operation of weapon systems are favorable would be desirable. Such a method will be described. It consists of reading the AWS data, interpolating to get the desired ceiling and visibility levels, converting the interpolated data into a joint probability distribution, averaging the data over several monthly or hourly periods, and assembling the resulting data to give probabilities of the weather states given in the linear model.

### SECTION III

#### METHOD

On the first step, the AWS data are read in. These data consist of a set  $C = \{C_1, \dots, C_n\}$  of ceiling levels, a set  $V = \{V_1, \dots, V_n\}$  of visibility levels, and a cumulative probability distribution  $F: C \times V \rightarrow [0,1]$  such that for all  $v$  in  $V$  and  $c$  in  $C$ , the number  $F(c,v)$  is the probability that the ceiling is  $\geq c$  and the visibility is  $\geq v$ . The AWS data are also dependent on the month  $m$  and the hour  $h$ , so that  $F$  is really a function of four variables  $c$ ,  $v$ ,  $m$ , and  $h$ .

The desired input to the linear model is given in terms of conditions on the ceiling and visibility values, such as "ceiling between 3,000 and 10,000 feet and visibility between 3 and 5 miles." Let  $C'$  be the set of all ceiling levels and let  $V'$  be the set of all visibility levels referred to in the conditions. In general,  $C'$  will contain some ceiling levels not contained in  $C$  and  $V'$  will contain some visibility levels not contained in  $V$ . The data must be expressed in terms of  $C'$  and  $V'$ , and to do this, the computer program interpolates between the nearest two values in  $C$  or  $V$  on either side of a given value  $c'$  in  $C'$  or  $v'$  in  $V'$ . Two interpolations are needed - one for ceilings and one for visibilities.

The method reported here uses a linear interpolation as follows: Given  $c'$  in  $C'$  and  $v'$  in  $V'$ , suppose that  $c'$  is not in  $C$  and  $v'$  is not in  $V$ . The level  $c'$  lies between the two nearest levels  $c^-$ ,  $c^+$  in  $C$ , i.e.,  $c^- < c' < c^+$ . Similarly, there are the two nearest levels  $v^+$  and  $v^-$  to  $v'$  in  $V$ , and  $v^- < v' < v^+$ . (Assumption is made that zero levels are included in  $C$ ,  $C'$ ,  $V$ ,  $V'$ , and that the highest levels in  $C$  and  $V$  exceed the highest levels in  $C'$  and  $V'$ ). Define

$$G'(c, v') = \left( \frac{v' - v^-}{v^+ - v^-} \right) (F(c, v^+) - F(c, v^-)) + F(c, v^-) \quad (1)$$

$$F'(c', v') = \left( \frac{c' - c^-}{c^+ - c^-} \right) (G(c^+, v') - G(c^-, v')) + G(c^-, v') \quad (2)$$

where  $G: C \times V' \rightarrow [0,1]$  is an intermediate step in the computation.

Then  $F'$  is considered to be a good approximation to the ceiling and visibility conditions at the levels contained in  $C'$  and  $V'$ . This constitutes a linear interpolation. A quadratic approximation would not be better, as demonstrated by the following example.

In one actual case involving Berlin (visibility 6 miles, October, 0000-0200 hours) the following probabilities are given.

Ceiling Level c (In Feet)	Probability That Visibility $\geq 6$ and That Ceiling $\geq c$
14,000	0.266
12,000	0.268
10,000	0.284

These three points in ceiling-probability space might be considered in order to obtain the probability that visibility  $\geq 6$  miles and that ceiling  $\geq 13,000$  feet. The resulting parabola is given by the equation

$$p(c) = 1.75 \times 10^{-9} c^2 - 4.65 \times 10^{-5} c + 0.574$$

It is required by the laws of probability that the requested probability at 6 miles, 13,000 feet, be greater than the probability at 6 miles, 14,000 feet. However,  $p(13,000) = 0.2652 < p(14,000) = 0.266$ . The problem is that the parabola dips, as Figure 1 demonstrates. This sort of situation was found to occur frequently in the AWS data. Hence a linear, rather than a quadratic, approximation was used.

If  $v'$  is in  $V$ , then the value  $G(c, v')$  is set equal to  $F(c, v')$ . Similarly, if  $c'$  is in  $C$ , then  $F'(c', v')$  is set equal to  $G(c', v')$ . These two steps have to be considered separately, since applying Equation (1) or (2) will result in division by zero.

After the data is interpolated, it is converted into a joint probability distribution. To do this, arrange the elements of  $C'$  and  $V'$  in descending order. Then  $v_1 \geq v_2 \geq \dots \geq v_n$  and  $c_1 \geq \dots \geq c_m$  (since there is no longer any need for  $C$  and  $V$ , the primes shall be dropped on the  $v$ 's and  $c$ 's). This implies for all  $k$  and for all  $i$  and  $j$  such that  $i < j$ , the inequalities

$$F(c_i, v_k) < F(c_j, v_k)$$

$$\text{and } F(c_k, v_i) < F(c_k, v_j)$$

hold. Define

$$K(c_i, v_j) = F(c_i, v_j) - F(c_i - 1, v_j), \text{ for } i = m-1, \dots, 1, \\ j = 1, \dots, n.$$

$$\text{and } J(c_i, v_j) = K(c_i, v_j) - K(c_i, v_{j-1}), \text{ for } j = n-1, \dots, 1 \\ i = 1, \dots, m.$$

where  $K$  is an intermediate computational function. In the computer program,  $F'$ ,  $J$ ,  $K$  are all stored in the same array, which makes it necessary to run through the indices backwards, as indicated above. For the remainder of this report,  $F$  will denote the function  $J$  as defined above.

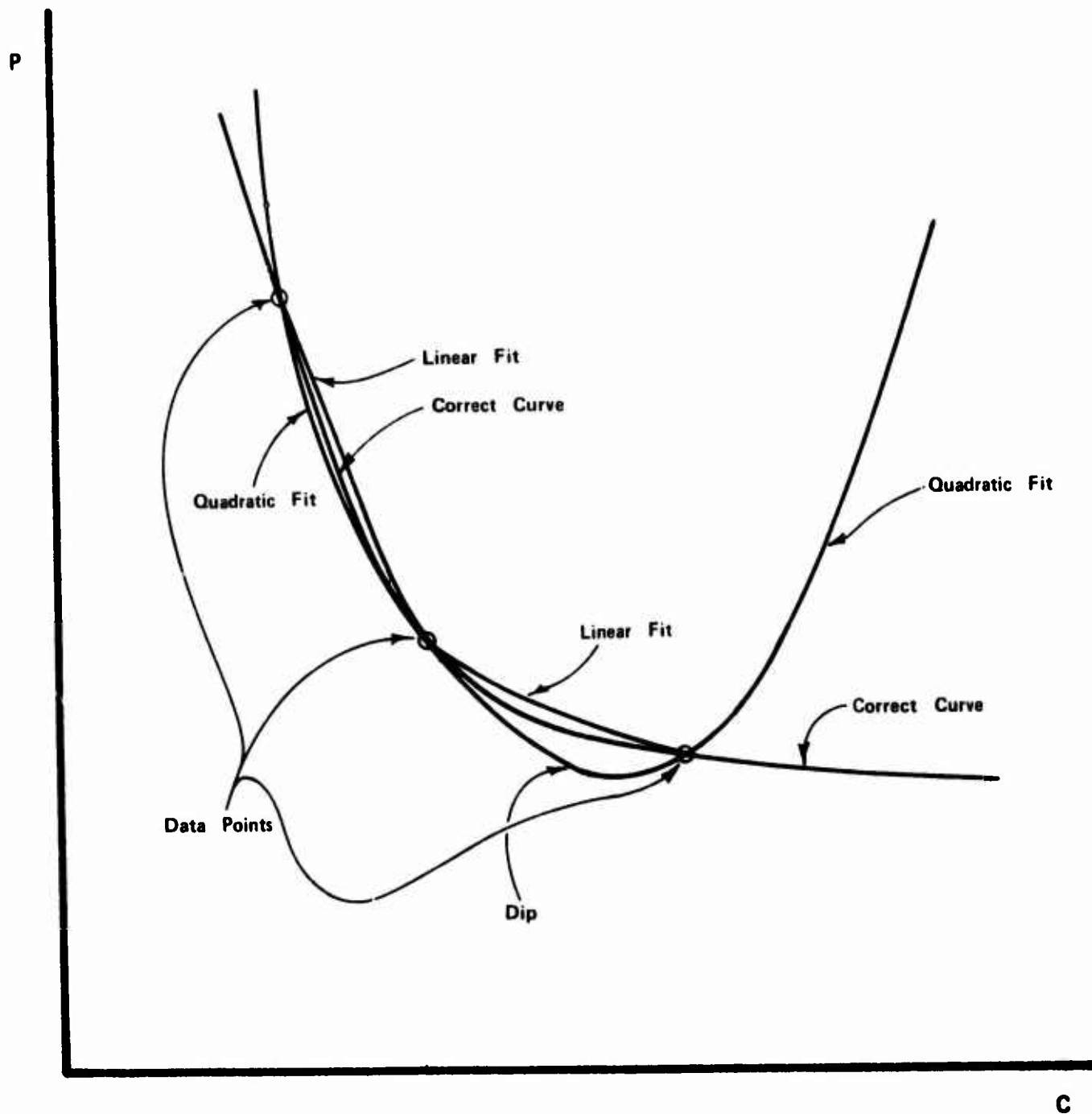


Figure 1. Collocating a Parabola Through Three Points in Ceiling-Probability Space

The next step is to average the data over a set of hourly periods or over a set of months. Two alternatives that were tried were:

(1) Averaging over best 3 months of year (or over the worst). Best was defined as the 3 months with the highest median ceiling (or highest probability of no ceiling, in case the median ceiling was infinity). A similar definition was used for worst.

(2) Averaging over best and worst 3-hour periods, separately for day and night. A 3-hour period was regarded as a day period if the sun was above the horizon more than 30 percent of the time during the period; otherwise, the period was a night period. To accomplish this averaging, separate arrays of ceiling and visibility probability data for each of the month-hour combinations to be considered were read in, interpolated and converted into joint distributions. They were then averaged together. In the results given in this report, no averaging took place.

The final step consisted of totaling the present set of data so that probabilities for the conditions required by the linear model could be calculated. These conditions can be expressed by giving a partition of the set  $C' \times V'$ :

$$C' \times V' = L_1 \cup L_2 \cup \dots \cup L_r,$$

where the unions are disjoint. The  $L$ 's can be thought of as weather states. For example, if  $C' = \{10000, 6000, 4000, 0\}$  and  $V' = \{10, 6, 4, 0\}$ , then a possible partition is as follows:

$$L_1 = \{ (10000, 10), (10000, 6), (10000, 4), (10000, 0) \}$$

$$L_2 = \{ (6000, 6), (6000, 4), (4000, 6), (4000, 4) \}$$

$$L_3 = \{ (6000, 10), (4000, 10) \}$$

$$L_4 = \{ (6000, 0), (4000, 0), (0, 10), (0, 6), (0, 4), (0, 0) \}$$

The interpretation of  $L_1$ ,  $L_2$ ,  $L_3$ , and  $L_4$  is as follows:

$L_1$  Ceiling  $\geq 10,000$  feet

$L_2$  Ceiling between 4,000 and 10,000 feet and visibility between 4 and 10 miles

$L_3$  Ceiling between 4,000 and 10,000 feet and visibility  $\geq 10$  miles

$L_4$  Ceiling  $\leq 4,000$  feet or visibility  $\leq 4$  miles and ceiling  $\leq 10,000$  feet

As the above descriptions show, the  $L_i$  can be described by specifying for each ceiling level the visibility levels contained in it. The algorithm then adds up the probabilities in each of the  $L_i$ 's to obtain the probability that each weather state will hold. In symbols,

$$p(L_i) = \sum_{(c,v) \in L_i} F(c,v) \quad \text{for } i = 1, \dots, r$$

These probabilities can then be used as data for the linear programming model of Speir (Reference 1).

## SECTION IV

### INPUT, OUTPUT AND EXAMPLE

To demonstrate the execution of this program, consider the following problem: Suppose a certain military operation is to be undertaken between 0000 and 0300 on 5 October 1980 near Berlin, Germany. To determine how the operation is to take place, it is desired to find the probability of the following weather states:

- (1) Ceiling  $\leq$  344 feet and Visibility  $\leq$  2.56 miles
- (2) 344 feet  $\leq$  Ceiling  $\leq$  1784 feet and Visibility  $\geq$  2.56 miles
- (3) 1784 feet  $\leq$  Ceiling  $\leq$  3033 feet and Visibility  $\geq$  2.56 miles
- (4) Ceiling  $\geq$  3033 feet and 2.56 miles  $\leq$  Visibility  $\leq$  5.12 miles
- (5) 3033 feet  $\leq$  Ceiling  $\leq$  9874 feet and Visibility  $\geq$  5.12 miles
- (6) Ceiling  $\geq$  9874 feet and Visibility  $\geq$  5.12 miles.

These are mutually exclusive. The data to be used in determining the above probabilities is the AWS data for October, 0000-0300 hours.

The input to be provided to the computer is the following:

1. Card 1 (I2, I1, 4I2)

MTY	Month
LHR	Hour Period (0000-0300 is 1, 0300-0600 is 2, etc.)
NC	Total number of ceiling levels referred to in description of weather states
NV	Total number of visibility levels referred to in description of weather states
IT	Total number of weather state descriptor cards (see below)
NWC	Number of weather states.

2. Card 2 (13F6.1)

The NC ceiling levels (in feet) in order from highest to lowest (XC(I), I=1,N).

3. Card 3 (13F6.1)

The NV visibility levels (in miles) in order from highest to lowest (XV(I), I=1,N).

4. Cards 4 to IT + 3 (414)

IT cards describing the weather states as follows:

NN(I) Number of weather state  
 NCN(I) Ceiling zone ( $XC(I) \leq level \leq (I-1)$ ) for which this card gives the visibility zones corresponding to the weather state I.  
 NVA(I) { The visibility level considered in this  
 NVB(I) { card is  $NVB(I) \leq level \leq NVA(I)$ .

As an example for this report the weather states can be indicated by the following:

Ceiling Levels (Feet)	Visibility Levels (Miles)		
	1	2	3
	5.12+	2.56-5.12	0-2.56
9874+	6	4	1
5942 - 9874	5	4	1
3033 - 5942	5	4	1
1784 - 3033	3	3	1
344 - 1784	2	2	1
0 - 344	1	1	1

Thus, to describe weather state 5, the following cards are used:

5 2 1 1  
 5 3 1 1

That is, weather state 5 consists of ceiling level 2(5942-9874 feet) at visibility level 1 (5.12+ miles) and ceiling level 3(3033-5942 feet) at visibility level 1 (5.12+ miles). Thus, the complete set of data for this problem is as follows:

101 6 314 6  
 9874. 5942. 3033. 1784. 344. 0.  
 5.12 2.56 0.  
 1 1 3 3  
 1 2 3 3  
 1 3 3 3  
 1 4 3 3  
 1 5 3 3  
 1 6 1 3  
 2 5 1 2  
 3 4 1 2  
 4 1 2 2

4	2	2	2
4	3	2	2
5	2	1	1
5	3	1	1
6	1	1	1

The original weather data should be on a TAPE 4 in binary format, giving first the month number, then the hour period number, then a series of data representing a 32x16 array containing the AWS data for the given month and hour period. The tape should give AWS data for all month-hour period combinations. The program advances TAPE 4 until the correct month-hour period is found according to the first data card. The program was run on a CDC 6600 with Scope 3.3; on another computer system some modifications of the program may have to be made.

The output has four parts:

1. Joint probability distribution of ceiling versus visibility for the ceiling and visibility data given.
2. Conditional probability of the ceiling levels given a certain visibility level.
3. Conditional probability of the visibility levels given a certain ceiling level.
4. Probabilities of the given weather states.

Note that in the output the figure 5942 as a ceiling level means ceiling between 5942 feet and the next highest ceiling level, i.e., 9874 feet. A listing of the FORTRAN IV program followed by results for this example are included in Appendix A.

## SECTION V

### CONCLUSIONS

The purpose of this report was to provide a method by which weather data provided by AWS can be converted into a form usable in weapons allocations programs, with Speir's program (Reference 1) specifically in mind. The methodology in the report is more important than the specific details. Although the original AWS data tapes have been purged and the data available only in table form, the program or a suitable modification of it will provide weather state data most of the time when it is needed.

APPENDIX A

FORTRAN IV WEATHER STATE PROGRAM  
AND  
RESULTS OF WEATHER STATE  
EXAMPLE



FTN 4.3+P393 13/06/75 08.07.01.

PROGRAM P9109 74/74 OPT=1

```

C
      ZN(J,K,3)=ZN(J,K,1)/CNSUM(J)
      ZN(J,K,2)=ZN(J,K,1)/VNSUM(K)
      DO 1000 I=1,3
      WRITE(6,109) NAME,MTM(MTY),HR(THR),(XWT(I,IO),I=1,6),(XV(I),I=1,NV)
      (V)
      100 FORMAT(1H1,5A10,10X,2A10//6X,8A10,'(FROM HOURLY OBSERVATIONS, INTE-
      -POLATED)')//35X,'VISIBILITY',CEILING/3X,'(FFET)',16(1X,F5.2)/
      //)
      DO 110 J=1,NC
      110 WRITE(6,111) JC(J),ZN(J,I,IO),I=1,NV
      111 FORMAT(1X,F6.0,15E6.3)
      1000 CONTINUE
      DO 500 N=1,NT
      502 PR(N)=0
      NVAD=NVA(N)
      NV80=NVS(N)
      DO 501 NA=NVAD,NV80
      501 PR(NM(N))=PR(NM(N))+ZN(NCN(N),NA,1)
      500 CONTINUE
      503 (I,PR(I),I=1,NMC)
      503 WRITE(6,503) (I,PR(I),I=1,NMC)
      503 FORMAT(1H1,15X,15(1X,F9.5))
      GO TO 3
      290 STOP
      END

```

STATES HAVE THE FOLLOWING PROPARILI

SUBROUTINE INTERP 74/74 NOT=1

```

1  SUBROUTINE INTERP(Z)
2  COMMON/CMC,NV,XC(12),XV(16),XCP(12),XVP(16)
3  DIMENSION Z(12,16),V(12,16),M(32,16)
4  LOGICAL GOTJ,GOTL
5  DO 1 I=1,NV
6  DO 1 L=1,NV
7  GOTL=.FALSE.
8  GOTJ=.FALSE.
9  DO 2 J=1,32
10 IF(XC(I).GT.XCP(J)) GO TO 30
11 IF(XC(I).EQ.XCP(J)) GO TO 30
12 GO TO 40
13 GOTJ=.TRUE.
14 GO TO 4
15 CONTINUE
16 DO 4 K=1,16
17 IF(XV(I).GT.XVP(K)) GO TO 50
18 IF(XV(I).EQ.XVP(K)) GO TO 50
19 GO TO 60
20 GOTL=.TRUE.
21 GO TO 5
22 CONTINUE
23 IF(GOTL) GO TO 60
24 V(J,L)=Z(J,K)
25 IF(GOTJ) V(J-1,L)=Z(J-1,K)
26 DO 60 J=1,32
27 V(J,K-1)=Z(J,K)
28 IF(J-1) V(J-1,K-1)=Z(J-1,K)
29 IF(XV(L)-XVP(K))+(XV(L)-XVP(K-1))-XVP(K)
30 1+(XV(L)-XVP(K))+(XV(L)-XVP(K-1))-XVP(K)
31 M(I,L)=V(J,L)
32 GO TO 75
33 M(I,L)=V(J-1,L)-V(J,L)/(XVP(J)-XVP(J-1))+V(J,L)
34 CONTINUE
35 DO 11 I=1,NV
36 DO 11 L=1,NV
37 Z(I,L)=M(I,L)
38 RETURN
39 END

```



BERLIN GER/TEMPLE OF CENTRAL APT 1947-1963  
WATER COMMUNITY DISTRIBUTION FOR CEILING VS. VISIBILITY

## VISIBILITY

[illegible]

BERLYN GER/TEMPLEHOFF CENTRAL APT 1947-1963  
PROBABILITY THAT CEILING IS -A- GIVEN THAT VISIBILITY IS -A-

## VISIBILITY

CEILING (FEET)	5.12	2.56	0.00
9874.	.494	.483	.365
9842.	.864	.005	.610
9833.	.188	.150	.013
11704.	.111	.091	.022
304.	.163	.104	.251
0.	0.000	.004	.519

OCTOBER 0000-0200  
(FROM HOURLY OBSERVATIONS, INTERPOLATED)

WELIN GEOTEMPLE OF CENTRAL APT 1947-1963  
PROBABILITY THAT THE VISIBILITY IS -9-, GIVEN THAT THE CEILING IS -A-

VISIBILITY

CEILING (FEET)	5-12	2-56	0-00
9874	.001	.221	.179
5942	.000	.360	.150
3033	.000	.201	.129
1704	.000	.215	.092
344	.000	.217	.202
0	.000	.014	.096

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THE FOLLOWING WEATHER STATES HAVE THE FOLLOWING PROBABILITIES-

1	2	3	4	5	6
.22605	.13141	.00155	.15154	.13207	.27658

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ASD/ENYS	1
AMXLE-PM	1